

CLAIMS

1. An apparatus for the discrimination of a matter utilizing acoustic force in field flow fractionation, which apparatus comprises:

5 a) a chamber having at least one inlet port and at least one outlet port, said chamber having such structural characteristics that when a carried medium is caused to travel through said chamber, the traveling velocity of said carried medium at various positions within said chamber is different;

10 b) at least one piezoelectric transducer adapted along a portion of said chamber, wherein said piezoelectric transducer can be energized via at least one electrical signal provided by an electrical signal generator to create an acoustic wave, thereby causing at least one acoustic force having components normal to the traveling direction of said carrier medium on a matter in said carrier medium.

15 2. The apparatus of claim 1, which comprises a plurality of inlet ports.

3. The apparatus of claim 1, which comprises a plurality of outlet ports.

20 4. The apparatus of claim 1, wherein the outlet port is connected to a collection device or characterization device.

25 5. The apparatus of claim 1, wherein the structural characteristics of the chamber are defined by the fact that the chamber's length is substantially greater than its width or height.

6. The apparatus of claim 1, which comprises a plurality of piezoelectric transducers.

30 7. The apparatus of claim 6, wherein the plurality of piezoelectric transducers are energized via common electrical signals or via different electrical signals.

8. The apparatus of claim 6, wherein the plurality of piezoelectric transducers are adapted along the interior or exterior surface of the chamber.

5 9. The apparatus of claim 6, wherein the plurality of piezoelectric transducers are configured on a plane substantially parallel to the traveling direction of the carrier medium travelling through the chamber.

10 10. The apparatus of claim 1, wherein the electrical signal generator for energizing the piezoelectric transducer to create the acoustic force is capable of varying magnitude and frequency of said electrical signals.

11. The apparatus of claim 1, wherein the chamber comprises a tube.

15 12. The apparatus of claim 11, wherein the piezoelectric transducer, or a plurality thereof, is adapted along the interior surface of the tube.

13. The apparatus of claim 11, wherein the piezoelectric transducer, or a plurality thereof, is adapted along the exterior surface of the tube.

20 14. The apparatus of claim 1, wherein the chamber comprises a top wall, a bottom wall, and two side walls.

25 15. The apparatus of claim 14, wherein the velocity of the carrier medium follows at different positions in the chamber is a parabolic or a near-parabolic flow profile.

30 16. The apparatus of claim 14, wherein the piezoelectric transducer, or a plurality thereof, is configured on the top wall of the chamber.

17. The apparatus of claim 14, wherein the piezoelectric transducer, or a plurality thereof, is configured on the bottom wall of the chamber.

18. The apparatus of claim 14, wherein the piezoelectric transducer, or a plurality thereof, is adapted on opposing surfaces of the chamber.

19. The apparatus of claim 14, wherein the chamber height between the top wall and bottom wall is about half wavelength of the standing acoustic wave.

20. The apparatus of claim 14, wherein the two side walls are parts of a gasket or spacer between the top and bottom walls and wherein a channel is cut in the gasket or spacer.

21. The apparatus of claim 20, wherein the channel has a shape selected from the group consisting of a rectangular, an elliptic and a circular shape.

22. The apparatus of claim 20, wherein the width of the channel is from about 1 mm to about 20 cm, and the height of the channel is from about 20 micron to about 10 mm, and the length of the channel is from about 1 cm to 200 cm.

23. An apparatus for the discrimination of a matter utilizing acoustic force in field flow fractionation, which apparatus consists essentially of:

a) a chamber having at least one inlet port and at least one outlet port, said chamber having such structural characteristics that when a carried medium is caused to travel through said chamber, the traveling velocity of said carried medium at various positions within said chamber is different;

b) at least one piezoelectric transducer adapted along a portion of said chamber, wherein said piezoelectric transducer can be energized via at least one electrical signal provided by an electrical signal generator to create an acoustic wave, thereby causing at least one acoustic force having components normal to the traveling direction of said carrier medium on a matter in said carrier medium.

24. An apparatus for the discrimination of a matter utilizing acoustic force in field flow fractionation, which apparatus consists of:

a) a chamber having at least one inlet port and at least one outlet port, said chamber having such structural characteristics that when a carried medium is caused to travel through said chamber, the traveling velocity of said carried medium at various positions within said chamber is different;

b) at least one piezoelectric transducer adapted along a portion of said chamber, wherein said piezoelectric transducer can be energized via at least one electrical signal provided by an electrical signal generator to create an acoustic wave, thereby causing at least one acoustic force having components normal to the traveling direction of said carrier medium on a matter in said carrier medium.

25. An apparatus for the discrimination of a matter utilizing electrophoretic and acoustic forces in field flow fractionation, which apparatus comprises:

a) a chamber having at least one inlet port and at least one outlet port, said chamber having such structural characteristics that when a carried medium is caused to travel through said chamber, the traveling velocity of said carried medium at various positions within said chamber is different;

b) at least two electrode elements adapted along a portion of said chamber, wherein said electrode elements can be energized via at least one electrical signal provided by an electrical signal generator to create an electrical field, thereby causing at least one electrophoretic force having components normal to the traveling direction of said carrier medium on a matter in said carrier medium; and

c) at least one piezoelectric transducer adapted along a portion of said chamber, wherein said piezoelectric transducer can be energized via at least one electrical signal provided by an electrical signal generator to create an acoustic wave, thereby causing at least one acoustic force having components normal to the traveling direction of said carrier medium on a matter in said carrier medium.

26. The apparatus of claim 25, which comprises more than two electrode elements.

27. The apparatus of claim 25, wherein each of more than two electrode elements is individually connected to one of a plurality of electrical conductor buses electrically connected to the electrical signal generator.

28. The apparatus of claim 25, wherein the electrode elements are adapted substantially longitudinally or latitudinally along a portion of the chamber.

29. The apparatus of claim 25, wherein the electrode elements are adapted along the interior surface of the chamber.

30. The apparatus of claim 25, wherein the electrode elements are configured on a plane substantially parallel to the traveling direction of carrier medium caused to travel through said chamber.

31. The apparatus of claim 25, wherein the electrode elements form an electrode array, said electrode array is selected from an interdigitated electrode array, interdigitated castellated electrode array, interdigitated electrode array having periodic triangular-shaped tips on the electrode elements, interdigitated electrode array having periodic arc-shaped tips on the electrode elements.

32. The apparatus of claim 25, wherein the electrode elements are a metal layer coated on a surface of the chamber.

33. The apparatus of claim 32, wherein the metal is selected from a group of gold, platinum, aluminum, chromium, titanium, copper and silver.

34. The apparatus of claim 25, wherein the electrical signal generator for energizing the electrode elements to create the electrophoretic force is a DC signal source

capable of varying magnitude of DC voltage, or is a AC signal source capable of varying magnitude and frequency, of said electrical signals.

5 35. The apparatus of claim 25, wherein the electrical signal for energizing the electrode elements to create the electrophoretic force is a DC electrical signal or a low-frequency-AC signal.

 36. The apparatus of claim 25, wherein the chamber comprises a tube.

10 37. The apparatus of claim 36, wherein the electrode elements and/or the piezoelectric transducer, or a plurality thereof, are adapted along the interior surface of the tube.

15 38. The apparatus of claim 36, wherein the electrode elements and/or the piezoelectric transducer, or a plurality thereof, are adapted along the exterior surface of the tube.

20 39. The apparatus of claim 25, wherein the chamber comprises a top wall, a bottom wall, and two side walls and the electrode elements and/or the piezoelectric transducer, or a plurality thereof, are configured on the top wall of the chamber.

25 40. The apparatus of claim 25, wherein the chamber comprises a top wall, a bottom wall, and two side walls and the electrode elements and/or the piezoelectric transducer, or a plurality thereof, are configured on the bottom wall of the chamber.

 41. The apparatus of claim 25, wherein the electrode elements and/or the piezoelectric transducer, or a plurality thereof, is adapted on opposing surfaces of the chamber.

30 42. An apparatus for the discrimination of a matter utilizing electrophoretic and acoustic forces in field flow fractionation, which apparatus consists essentially of:

a) a chamber having at least one inlet port and at least one outlet port, said chamber having such structural characteristics that when a carried medium is caused to travel through said chamber, the traveling velocity of said carried medium at various positions within said chamber is different;

5 b) at least two electrode elements adapted along a portion of said chamber, wherein said electrode elements can be energized via at least one electrical signal provided by an electrical signal generator to create an electrical field, thereby causing at least one electrophoretic force having components normal to the traveling direction of said carrier medium on a matter in said carrier medium; and

10 c) at least one piezoelectric transducer adapted along a portion of said chamber, wherein said piezoelectric transducer can be energized via at least one electrical signal provided by an electrical signal generator to create an acoustic wave, thereby causing at least one acoustic force having components normal to the traveling direction of said carrier medium travelling through said chamber on said matter in said carrier medium.

15
43. An apparatus for the discrimination of a matter utilizing electrophoretic and acoustic forces in field flow fractionation, which apparatus consists of:

20 a) a chamber having at least one inlet port and at least one outlet port, said chamber having such structural characteristics that when a carried medium is caused to travel through said chamber, the traveling velocity of said carried medium at various positions within said chamber is different;

25 b) at least two electrode elements adapted along a portion of said chamber, wherein said electrode elements can be energized via at least one electrical signal provided by an electrical signal generator to create an electrical field, thereby causing at least one electrophoretic force having components normal to the traveling direction of said carrier medium on a matter in said carrier medium; and

30 c) at least one piezoelectric transducer adapted along a portion of said chamber, wherein said piezoelectric transducer can be energized via at least one electrical signal provided by an electrical signal generator to create an acoustic wave, thereby causing at least one acoustic force having components normal to the traveling direction of

said carrier medium travelling through said chamber on said matter in said carrier medium.

44. An apparatus for the discrimination of a matter utilizing dielectrophoretic and acoustic forces in field flow fractionation, which apparatus comprises:

a) a chamber having at least one inlet port and at least one outlet port, said chamber having such structural characteristics that when a carried medium is caused to travel through said chamber, the traveling velocity of said carried medium at various positions within said chamber is different;

b) at least two electrode elements adapted along a portion of said chamber, wherein said electrode elements can be energized via at least one electrical signal provided by an electrical signal generator to create a non-uniform electrical field, thereby causing at least one dielectrophoretic force having components normal to the traveling direction of said carrier medium on a matter in said carrier medium; and

c) at least one piezoelectric transducer adapted along a portion of said chamber, wherein said piezoelectric transducer can be energized via at least one electrical signal provided by an electrical signal generator to create an acoustic wave, thereby causing at least one acoustic force having components normal to the traveling direction of said carrier medium on a matter in said carrier medium.

45. The apparatus of claim 44, which comprises more than two electrode elements.

46. The apparatus of claim 45, wherein each of more than two electrode elements is individually connected to one of a plurality of electrical conductor buses electrically connected to the electrical signal generator.

47. The apparatus of claim 45, wherein the electrode elements further creates a spatially inhomogeneous electric field.

48. The apparatus of claim 44, wherein the electrical signal generator for energizing the electrode elements to create the dielectrophoretic force is capable of varying magnitude, and frequency of said electrical signals.

5 49. An apparatus for the discrimination of a matter utilizing dielectrophoretic and acoustic forces in field flow fractionation, which apparatus consists essentially of:

a) a chamber having at least one inlet port and at least one outlet port, said chamber having such structural characteristics that when a carried medium is caused to travel through said chamber, the traveling velocity of said carried medium at various
10 positions within said chamber is different;

b) at least two electrode elements adapted along a portion of said chamber, wherein said electrode elements can be energized via at least one electrical signal provided by an electrical signal generator to create a non-uniform electrical field, thereby causing at least one dielectrophoretic force having components normal to the traveling
15 direction of said carrier medium on a matter in said carrier medium; and

c) at least one piezoelectric transducer adapted along a portion of said chamber, wherein said piezoelectric transducer can be energized via at least one electrical signal provided by an electrical signal generator to create an acoustic wave, thereby causing at least one acoustic force having components normal to the traveling direction of
20 said carrier medium on a matter in said carrier medium.

50. An apparatus for the discrimination of a matter utilizing dielectrophoretic and acoustic forces in field flow fractionation, which apparatus consists of:

a) a chamber having at least one inlet port and at least one outlet port, said
25 chamber having such structural characteristics that when a carried medium is caused to travel through said chamber, the traveling velocity of said carried medium at various positions within said chamber is different;

b) at least two electrode elements adapted along a portion of said chamber, wherein said electrode elements can be energized via at least one electrical signal
30 provided by an electrical signal generator to create a non-uniform electrical field, thereby

causing at least one dielectrophoretic force having components normal to the traveling direction of said carrier medium on a matter in said carrier medium; and

c) at least one piezoelectric transducer adapted along a portion of said chamber, wherein said piezoelectric transducer can be energized via at least one electrical signal provided by an electrical signal generator to create an acoustic wave, thereby causing at least one acoustic force having components normal to the traveling direction of said carrier medium on a matter in said carrier medium.

51. A method of discriminating a matter using acoustic force in field flow fractionation, which method comprises:

a) obtaining an apparatus of claim 1;
b) introducing a carrier medium containing a matter to be discriminated into the chamber of the apparatus of the claim 1 via its inlet port, wherein said introducing causes the carrier medium to travel through the chamber according to a velocity profile;
c) applying at least one electrical signal provided by an electrical signal generator to the piezoelectric transducer, wherein said energized piezoelectric transducer creates an acoustic wave, thereby causing at least one acoustic force on said matter having components normal to the traveling direction of said carrier medium travelling through said chamber;

whereby said matter is displaced to positions within said carrier medium along a direction normal to the traveling direction of said carrier medium travelling through said chamber and discriminated according to its position within said carrier medium along the direction normal to the traveling direction of said carrier medium travelling through said chamber.

52. The method of claim 51, wherein the matter is discriminated according to the velocity profile of carrier medium travelling through the chamber and the matter moves within the chamber at velocities dependent on its displacement within the velocity profile.

53. The method of claim 51, wherein the displaced matter exits from the outlet port of the chamber at time intervals dependent on its displacement within the velocity profile.

5 54. The method of claim 51, wherein the displaced matter exits from one of a plurality of the outlet ports of the chamber dependent on its displacement within the velocity profile.

10 55. The method of claim 51, wherein the gravitational force acting on the matter acts in a direction normal to the traveling direction of the carrier medium in the chamber.

15 56. The method of claim 51, wherein the matter to be discriminated is selected from the group consisting of a cell, a cellular organelle, a virus, a molecule and an aggregate or complex thereof.

20 57. The method of claim 56, wherein the cell is selected from the group consisting of an animal cell, a plant cell, a fungus cell, a bacterium cell, a cultured and a recombinant cell.

25 58. The method of claim 56, wherein the cellular organelle is selected from the group consisting of a nuclei, a mitochondrion, a chloroplast, a ribosome, an ER, a Golgi apparatus, a lysosome, a proteasome, a secretory vesicle, a vacuole and a microsome.

59. The method of claim 56, wherein the molecule is selected from the group consisting of an inorganic molecule, an organic molecule and a complex thereof.

30 60. The method of claim 59, wherein the inorganic molecule is an ion selected from the group consisting of a sodium, a potassium, a magnesium, a calcium, a chlorine,

an iron, a copper, a zinc, a manganese, a cobalt, an iodine, a molybdenum, a vanadium, a nickel, a chromium, a fluorine, a silicon, a tin, a boron and an arsenic ion.

5 61. The method of claim 59, wherein the organic molecule is selected from the group consisting of an amino acid, a peptide, a protein, a nucleoside, a nucleotide, an oligonucleotide, a nucleic acid, a vitamin, a monosaccharide, an oligosaccharide, a carbohydrate, a lipid and a complex thereof.

10 62. The method of claim 51, wherein the dimension of the matter to be discriminated is from about 0.01 micron to about 1000 micron.

63. A method of discriminating a matter using acoustic force in field flow fractionation, which method comprises:

- 15 a) obtaining an apparatus of claim 1;
b) loading a carrier medium into the chamber of apparatus of claim 1 via its inlet port until the chamber is filled with the carrier medium;
c) delivering a sample that contains a matter to be discriminated into the carrier medium in the chamber;
20 d) applying at least one electrical signal provided by an electrical signal generator to the piezoelectric transducer, wherein said energized piezoelectric transducer creates an acoustic wave, thereby causing at least one acoustic force on said matter;
e) introducing the carrier medium into the chamber of the apparatus via its inlet port, wherein said introducing causes the carrier medium to travel through the chamber according to a velocity profile,

25 whereby said matter is displaced to positions within said carrier medium along a direction normal to the traveling direction of said carrier medium travelling through said chamber and discriminated according to its position within said carrier medium along the direction normal to the traveling direction of said carrier medium travelling through said chamber.
30

64. The method of claim 63, wherein applying electrical signal to the piezoelectric transducer to cause acoustic force on said matter results in the matter being displaced into equilibrium position along a direction normal to the traveling direction of the carrier medium traveling through the chamber, prior to the introducing of carrier medium into the chamber that causes the carrier medium to travel through the chamber according to a velocity profile.

65. A method of discriminating a matter using electrophoretic and acoustic forces in field flow fractionation, which method comprises:

- a) obtaining an apparatus of claim 25;
- b) introducing a carrier medium containing a matter to be discriminated into the chamber of the apparatus of claim 25 via its inlet port, wherein said introducing causes the carrier medium to travel through the chamber according to a velocity profile;
- c) applying at least one electrical signal provided by an electrical signal generator to the electrode elements, wherein said energized electrode elements create an electrical field, thereby causing at least one electrophoretic force on said matter having components normal to the travelling direction of said carrier medium travelling through said chamber; and
- d) applying at least another electrical signal provided by an electrical signal generator to the piezoelectric transducer, wherein said energized piezoelectric transducer creates an acoustic wave, thereby causing at least one acoustic force on said matter having components normal to the traveling direction of said carrier medium travelling through said chamber;

whereby said matter is displaced to positions within said carrier medium along a direction normal to the traveling direction of said carrier medium travelling through said chamber and discriminated according to its position within said carrier medium along the direction normal to the traveling direction of said carrier medium travelling through said chamber.

66. The method of claim 65, wherein the electrophoretic force and the acoustic force are generated simultaneously.

67. The method of claim 65, wherein the electrophoretic force and the acoustic force are generated sequentially.

5 68. A method of discriminating a matter using electrophoretic and acoustic forces in field flow fractionation, which method comprises:

a) obtaining an apparatus of claim 25;

b) loading a carrier medium into the chamber of apparatus of claim 25 via its inlet port until the chamber is filled with the carrier medium;

10 c) delivering a sample that contains a matter to be discriminated into the carrier medium in the chamber;

d) applying at least one electrical signal provided by an electrical signal generator to the electrode elements, wherein said energized electrode elements create an electrical field, thereby causing at least one electrophoretic force on said matter;

15 e) applying at least another electrical signal provided by an electrical signal generator to the piezoelectric transducer, wherein said energized piezoelectric transducer creates an acoustic wave, thereby causing at least one acoustic force on said matter;

20 f) introducing the carrier medium into the chamber of the apparatus via its inlet port, wherein said introducing causes the carrier medium to travel through the chamber according to a velocity profile;

25 whereby said matter is displaced to positions within said carrier medium along a direction normal to the traveling direction of said carrier medium travelling through said chamber and discriminated according to its position within said carrier medium along the direction normal to the traveling direction of said carrier medium travelling through said chamber.

30 69. The method of claim 68, wherein applying electrical signal to the electrode elements to cause at least one electrophoretic force on said matter and applying electrical signal to the piezoelectric transducer to cause at least one acoustic force on said matter result in the matter being displaced into equilibrium position along a direction normal to the traveling direction of the carrier medium traveling through the chamber,

prior to the introducing of carrier medium into the chamber that causes the carrier medium to travel through the chamber according to a velocity profile.

5 70. The method of claim 68, wherein the electrophoretic force and the acoustic force are generated simultaneously.

 71. The method of claim 68, wherein the electrophoretic force and the acoustic force are generated sequentially.

10 72. A method of discriminating a matter using dielectrophoretic and acoustic forces in field flow fractionation, which method comprises:

- 15 a) obtaining an apparatus of claim 44;
- b) introducing a carrier medium containing a matter to be discriminated into the chamber of the apparatus of the claim 44 via its inlet port, wherein said introducing causes the carrier medium to travel through the chamber according to a velocity profile;
- 20 c) applying at least one electrical signal provided by an electrical signal generator to the electrode elements, wherein said energized electrode elements create a non-uniform electrical field, thereby causing at least one dielectrophoretic force on said matter having components normal to the traveling direction of said carrier medium travelling through said chamber; and
- 25 d) applying at least another electrical signal provided by an electrical signal generator to the piezoelectric transducer, wherein said energized piezoelectric transducer creates an acoustic wave, thereby causing at least one acoustic force on said matter having components normal to the traveling direction of said carrier medium travelling through said chamber;

30 whereby said matter is displaced to positions within said carrier medium along a direction normal to the traveling direction of said carrier medium travelling through said chamber and discriminated according to its position within said carrier medium along the direction normal to the traveling direction of said carrier medium travelling through said chamber.

73. The method of claim 72, wherein the dielectrophoretic force and the acoustic force are generated simultaneously.

74. The method of claim 72, wherein the dielectrophoretic force and the acoustic force are generated sequentially.

75. A method of discriminating a matter using dielectrophoretic and acoustic forces in field flow fractionation, which method comprises:

- a) obtaining an apparatus of claim 44;
- b) loading a carrier medium into the chamber of the apparatus of claim 44 via its inlet port until the chamber is filled with the carrier medium;
- c) delivering a sample that contains a matter to be discriminated into the carrier medium in the chamber;
- d) applying at least one electrical signal provided by an electrical signal generator to the electrode elements, wherein said energized electrode elements create an electrical field, thereby causing at least one dielectrophoretic force on said matter;
- e) applying at least another electrical signal provided by an electrical signal generator to the piezoelectric transducer, wherein said energized piezoelectric transducer creates an acoustic wave, thereby causing at least one acoustic force on said matter;
- f) introducing the carrier medium into the chamber of the apparatus via its inlet port, wherein said introducing causes the carrier medium to travel through the chamber according to a velocity profile;

whereby said matter is displaced to positions within said carrier medium along a direction normal to the traveling direction of said carrier medium travelling through said chamber and discriminated according to its position within said carrier medium along the direction normal to the traveling direction of said carrier medium travelling through said chamber.

76. The method of claim 75, wherein applying electrical signal to the electrode elements to cause dielectrophoretic force on said matter and applying electrical signal to the piezoelectric transducer to cause acoustic force on said matter result in the

5

10

sd-15038